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BLACS — A NEW CORRECTION SCHEME OF ANALOG ACCELEROGRAMS. PART – 2: COMPARISON WITH OTHER SCHEMES

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Abstract

In the first part of this paper a correction scheme, named as Band Limited Accelerogram Correction Scheme *(BLACS)* is presented for processing the records of analog accelerograph. In this part of the paper, comparison of this scheme is made with those of Lee and Trifunac, Erdik and Kubin and that of Khemici and Chiang. This is studied by comparing the response of the various schemes as well as their segments to white noise input which is assumed as uncorrected accelerogram. This comparison clearly brings out the advantages of using *BLACS*. A comparison is also done by affecting corrections on four uncorrected accelerograms using these schemes. The comparison is presented in a tabular form in frequency domain. A comparison is also presented by plotting response spectra of the corrected accelerograms obtained for the four earthquakes by *BLACS* with those of scheme of Lee and Trifunac. These results indicate that it is important to control the frequency contents of the data while processing as otherwise the final results may be substantially different.

INTRODUCTION

A study is made to compare the proposed scheme *(BLACS)* with three other schemes, namely those of Lee and Trifunac (1979), Erdik and Kubin (1984) and Khemici and Chiang (1984). Schemes of Lee and Trifunac (referred as Trifunac scheme) and of Erdik and Kubin (referred as Erdik scheme) are in time domain whereas the scheme of Khemici and Chiang (referred as Khemici scheme) is in frequency domain. In what follows a brief description is given about the correction procedure adopted by above mentioned three schemes and their response are studied for white noise input. The characteristics of instrument correction and band pass filter algorithms of these three schemes and that of *BLACS* are compared through the Fourier magnitude of their response to white noise. Comparison of the four schemes is also performed by plotting one over the other, the Fourier transformation of the response of the entire correction schemes to the white noise input. Uncorrected accelerograms of El Centro, Parkfield, Taft and Uttarkashi are corrected using the four schemes. Maximum values of acceleration, velocity and displacement and the time of their occurence as obtained in each case for the above mentioned records are compared. Fourier transformation of these corrected accelerograms obtained through each scheme are compared by dividing the band upto Nyquist frequency into sixteen segments and taking mean of each of the segment. Response spectra of the corrected accelerogram obtained from *(BLACS)* is determined and is plotted over the response spectra determined through the Trifunac scheme.

EVALUATION OF TRANSFER FUNCTION OF VARIOUS SCHEMES

In this part of work details of Trifunac, Erdik and Khemici schemes are discussed and their transfer function are evaluated by taking white noise as an uncorrected accelerogram. The sampling rate of white noise is as per specifications of the individual schemes discussed herein.

TRIFUNAC SCHEME

Trifunac scheme also known as Caltech data correction scheme was perhaps the first comprehensive scheme developed for processing accelerograms. This scheme is well documented and was quite popular till early eighties. Large number of accelerograms obtained in the past earthquakes have been processed with this scheme and are documented in reports published by Earthquake Engineering Research Laboratory (EERL) of California Institute of Technology. These corrected accelerograms, response spectra and Fourier spectra have become a valuable data and which are used by research workers for different applications in the field of Earthquake Engineering. It is for this reason that Trifunac scheme has been chosen here for the purpose of comparison. The computer code in FORTRAN is available for this scheme in Report no. 79-15 Volumes I and II of University of Southern California. The computer program of Volume II is used here with minor modification particularly in handling input and output files.

Although the entire correction scheme is quite intricate, the salient points of the scheme is being described briefly in following steps.

1. First, the uncorrected accelerogram is made from the digitized data of the earthquake record, time mark and fixed trace, almost in the same manner as is described for *BLACS* in Part:1 of this paper.
2. This uncorrected accelerogram is linearly interpolated to get the sequence at a uniform interval at 200 SPS.
3. This uncorrected accelerogram is then low pass filtered using Ormsby filter in time domain. The filter weights of the Ormsby filter are found by a standard formulation. Number of filter weights are dependent upon the roll off of the filter and the sampling interval. If f_r is the roll off of the required filter and T is the

sampling interval then the number of filter weights N_w required by the Ormsby filter is

$$N_w = \frac{1}{f_r T} \tag{1}$$

In this scheme, the cut off frequency of the low pass filter is taken as 25 Hz with roll off of 2 Hz. With the sampling period of 0.005 *second* (200 SPS), the number of filter weights required will be 100. A time domain convolution is performed between the uncorrected accelerogram and unit impulse response function of the Ormsby filter as defined by its weights, to get the low passed accelerogram.

4. Instrument correction is next performed on this 200 SPS low passed data to estimate ground acceleration from the approximate accelerations of uncorrected accelerogram. If ω_n is the natural frequency, ς the fraction of critical damping of the pendulum of the accelerometer and $a(t)$ the true ground acceleration, then the equation of motion of accelerometer is given by

$$\ddot{x}(t) + 2\omega_n \varsigma \dot{x}(t) + \omega_n^2 x(t) = -a(t) \tag{2}$$

   where $x(t)$ is the relative displacement of the pendulum, $\dot{x}(t)$ the first derivative and $\ddot{x}(t)$ the second derivative of relative displacement of the pendulum. The true acceleration $a(t)$ is found by determining $\dot{x}(t)$ and $\ddot{x}(t)$ from the known $-\omega_n^2 x(t)$ and putting these values in Equation 2. In this scheme the differentiation is performed using second order central difference approximation.

5. The instrument corrected sequence at 200 SPS is decimated to 50 SPS sequence by keeping only every fourth sample.

6. These data are then high pass filtered to remove low frequency noise using Ormsby filter with cutoff frequency generally 0.07 Hz and roll off of 0.05 Hz. For a roll off of 0.05 Hz and sampling rate of 50 SPS, the number of weights required in Ormsby filter will be 1000 as per Equation 1. To reduce computational work, the convolution is performed after decimating the signal to 5 SPS (sampling period of 0.2 *second*) thus reducing the number of weights of Ormsby filter to 100. The convoluted signal is then linearly interpolated to get the sequence at 50 SPS which when subtracted from the original sequence (which is also convoluted with a rectangular window) yielded the high pass filtered sequence which is the corrected accelerogram at 50 SPS.

7. The velocity and displacement sequences are obtained by integration using trapazoidal rule and zero initial conditions. These sequences are also high pass filtered as in step 6.

To evaluate the performance of this scheme, a white noise of 200 SPS and having 2048 data points is assumed as uncorrected accelerogram obtained from step 2. This is processed with the above scheme assuming natural frequency of accelerometer as 20 Hz and damping of 60% of critical. The cutoff frequency of low pass filter is taken as 25 Hz with a roll off of 2 Hz and the cutoff frequency of high pass filter is taken as 0.07 Hz

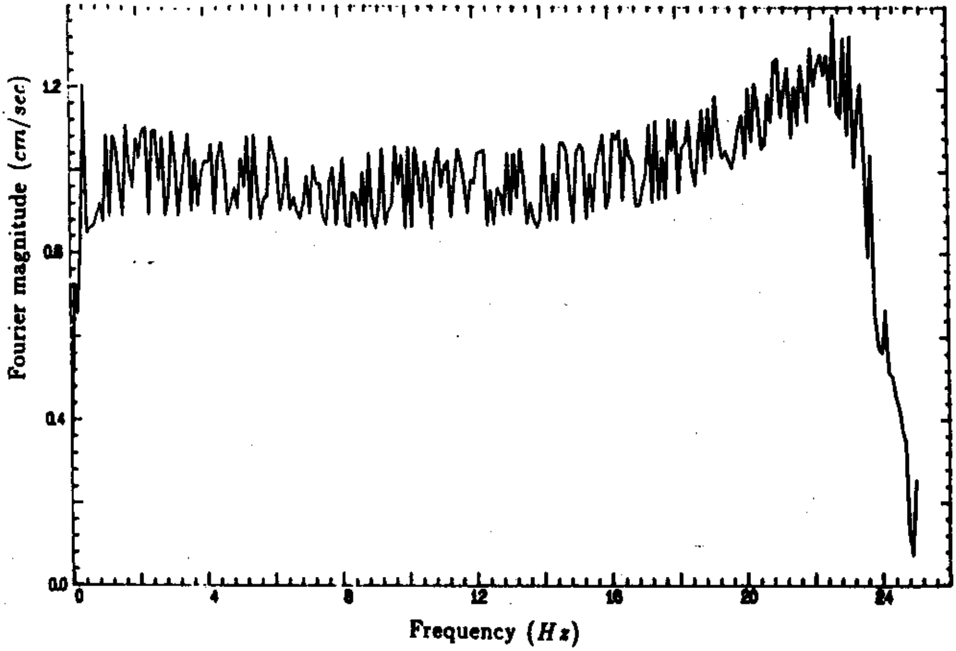

Figure 1: Fourier magnitude plot of Response of Trifunac's scheme to white noise input

with a roll off of 0.05 Hz. The corrected acceleration sequence at 50 SPS after step 6 is determined and Fourier transformation of this sequence is taken. Figure 1 gives the Fourier magnitude plot of the response of the scheme to white noise. In comparison to *BLACS* (Fig. 6 of Part:1 of this paper) it can be seen that the response of Trifunac scheme has jitters in the pass band.

ERDIK SCHEME

The basic steps of this correction scheme are as follows:

1. Nonuniform sampled uncorrected accelerogram is linearly interpolated to get uniform sampled sequence at 100 SPS.
2. This uncorrected accelerogram is low pass filtered in time domain using Ormsby filter in the same way as in the Trifunac scheme.
3. Data is then linearly interpolated to 200 SPS and instrument correction is performed in a manner as in the case of Trifunac scheme. This data is decimated back to 100 SPS data by dropping every alternate points.
4. A least square line is fitted in the instrument corrected sequence and the values of accelerations are adjusted accordingly.

5. The resulting acceleration is integrated in time domain through trapasoidal rule to obtain the velocity sequence assuming zero initial condition.

6. Cut off frequency of high pass filter is found by assuming that the Fourier magnitude of actual ground signal have a slope of -1 in the low frequency end. A plot of Fourier magnitude of uncorrected accelerogram is then used to recognise the frequency below which it deviates from the above property. This frequency is used as the cutoff frequency of the high pass filter to remove low frequencies.

7. The velocity sequence obtained from step 5 is high pass filtered with a cutoff frequency determined in step 6. A second order Butterworth filter is used in time domain to perform this high pass filtering. To avoid the nonlinear phase shift during the filtering, the sequence is filtered again with reverse time. This output when again reversed in time give high passed velocity sequence without any phase shift. This actually amounts to using $|H(j\omega)|^2$ of second order Butterworth filter.

8. A straight line is least square fitted to the velocity sequence obtained from step 7 and values of velocity are adjusted accordingly.

9. This velocity sequence is integrated to obtain the displacement sequence assuming zero initial condition.

10. A straight line is least square fitted to the displacement sequence obtained from step 9 and values of displacement are adjusted accordingly to obtain corrected displacement data.

11. The slope of the straight line of step 10 is added to the velocity sequence obtained after step 8 to get the corrected velocity data.

12. The corrected velocity is differentiated to get acceleration by using the FIR type linear phase digital differential filter as given by McClellan *et al.* (1973). The details of the digital filter designed in the present work to perform the required differentiation in this scheme is as follows:

    Filter length = 9
    Upper band edge = 0.30
    Peak relative error = 0.0032

    The impulse response factors obtained for above design are as following

$$
\begin{aligned}
h(1) &= -0.29521044E-02 = -h(9)\\
h(2) &= 0.15048594E-01 = -h(8)\\
h(3) &= -0.53063691E-01 = -h(7)\\
h(4) &= 0.14027159E+00 = -h(6)\\
h(5) &= 0.0
\end{aligned}
$$

where $h(1)$ to $h(9)$ are the weights of the FIR differentiator.

13. The obtained acceleration sequence is low pass filtered using Ormsby filter with the same filtering limits as of step 2. This yields corrected accelerogram.

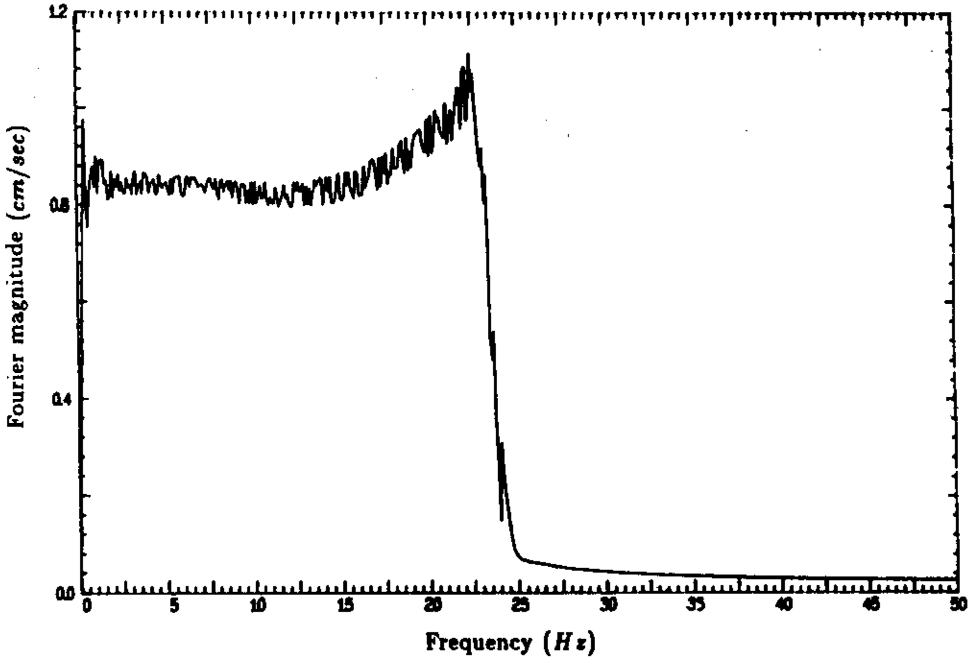

Figure 2: Fourier magnitude plot of Response of Erdik's scheme to white noise input

To evaluate the performance of this scheme, a white noise of 100 *SPS* and having 1024 data points is assumed as uncorrected accelerogram obtained from step 1. This is processed with the above scheme with the same accelerometer and filter specifications as used for Trifunac scheme. The corrected acceleration sequence after step 13 at 100 *SPS* is determined. Fourier transformation of this sequence is taken. Figure 2 gives the Fourier magnitude plot of the response of the scheme to white noise. In comparison to Trifunac scheme it can be seen that the response of this scheme is quite similar with jitters in the pass band. However, the jitters are smaller because the entire processing in this scheme is done at 100 *SPS* whereas it is done at 50 *SPS* in the Trifunac scheme. However, in comparison to the response to *BLACS* (Fig. 6 of Part:1 of this paper) the response of this scheme is jittery in the pass band and also frequency magnitude plot is approximately flat around 0.82 instead of unity.

KHEMICI SCHEME

The scheme of Khemici and Chiang which they refer as Stanford Accelerogram Correction Procedure (SACP) is in frequency domain and *BLACS* is quite similar to this scheme in several aspects. However, Khemici scheme has not suggested any method to interpolate the nonuniformly and uniformly spaced samples so that the frequency contents of the data do not change after interpolation. Khemici scheme starts with uniformly spaced uncorrected accelerogram. The instrument correction is performed in frequency domain in exactly the same fashion as discussed for *BLACS* in the first part of this paper. The band pass filtering is performed by using a filter function which has unit gain in pass band, half cosine tapering in the transition bands and zero gain in the stop band. This filter function has only real values and therefore the filtering operation does not introduce any phase shift. The transfer functions of instrument correction and that of band pass filter are multiplied to obtain the overall transfer function of the scheme. The Fourier transformation of uncorrected accelerogram is found which on convolution with the transfer function of the scheme gives the Fourier transformation of the corrected accelerogram, an inverse Fourier transform of which yields corrected accelerogram. Integration of corrected accelerogram to get velocity and displacement are performed in frequency domain.

To check the performance of this scheme, a white noise input at 100 *SPS* in the similar manner as it is given in the earlier section is imparted in this scheme with same accelerometer and filter specifications. The Fourier magnitude plot of the corrected sequence obtained is given in Fig. 3. It can be seen that the response of this scheme is similar to the proposed scheme with no jitters in the pass band. It may, however, be noted that the similarity between this scheme and the proposed scheme exists only in response of instrument correction and band pass filter to white noise. However, the effect of band limited interpolation of nonuniform samples as suggested in *BLACS* could not be studied here due to the fact that white noise with nonuniform samples could not be generated. Similarily, the effect of band limited interpolation of the uniform samples to increase the sampling rate of the corrected accelerogram as suggested in *BLACS* in comparison to the prevalent linear interpolation, has not been studied here. This part will be discussed in the next Section of this Chapter.

COMPARATIVE STUDY OF VARIOUS SCHEMES TO WHITE NOISE

Some important sections of the schemes are studied separately to compare their performance for white noise input. In this regard the instrument correction and low pass filter are studied. Next a comparison of overall transfer function of the various schemes is made with white noise input (uncorrected accelerogram) with a constraint that the corrected accelerogram is needed at 200 *SPS*.

INSTRUMENT CORRECTION

A white noise of 200 *SPS* with 2048 data points is generated. The instrument correction of this white noise is performed in time domain (as per scheme of Trifunac scheme and Erdik scheme) assuming natural frequency of accelerometer as 20 *Hz* and damping 60% of critical. Similarily instrument correction of this white noise is performed in frequency domain (as per *BLACS* and Khemici scheme) for the same specifications of accelerometer. The Fourier spectra of the instrument corrected data by the two methods are determined and their Fourier magnitudes are plotted one over the other as shown in Fig. 4 (upto 50 *Hz*). The plot shows that the frequency domain instrument correction

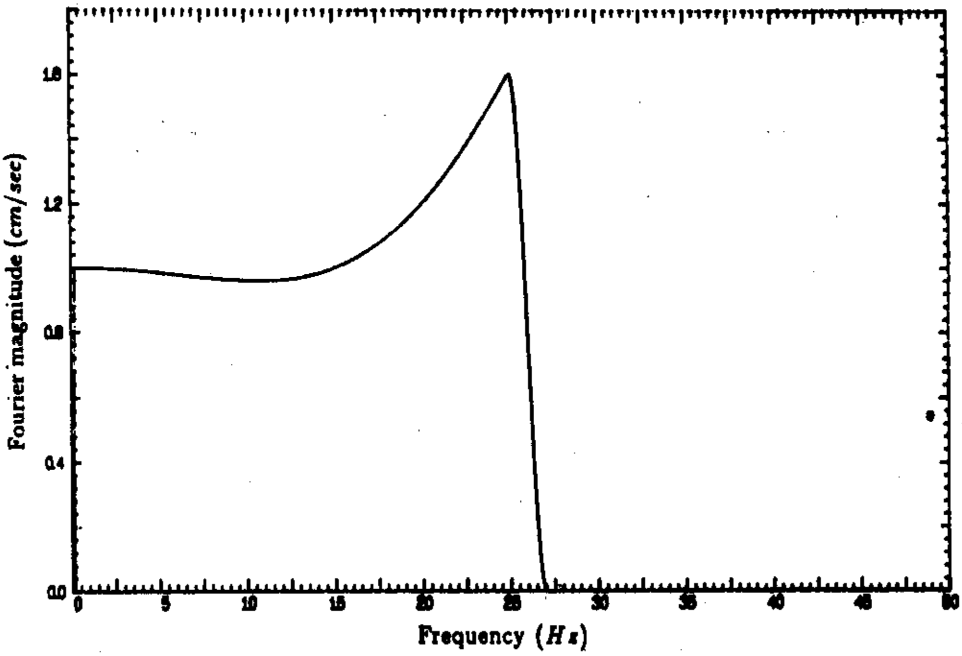

Figure 3: Fourier magnitude plot of Response of Khemici's scheme to white noise input

matches exactly with the ideal instrument correction process while the time domain correction process using central difference scheme is jittery and drops down at higher frequencies in comparison to ideal case.

LOW PASS FILTER

Similarily performance of low pass filter of different schemes to 200 *SPS* white noise with 2048 data points are studied next. The two time domain schemes use Ormsby filter as low pass filter, whereas, *BLACS* uses Butterworth filter (order 6) and Khemici scheme uses half cosine tapering. The convolution with white noise of filter of the later two is done in frequency domain. The low passed sequence of all the three filters for white noise input are found. The Fourier magnitudes of these schemes are plotted one over the other as shown in Fig. 5. All the three low pass filters perform more or less similarily except that the response of the Ormsby filter shows jitters in the pass band whereas the response of Butterworth filter and half cosine filters show smooth pass band as well as transition band. The jitters in the response of Ormsby filter has occured due to the fact that the convolution is done in time domain and the response is being viewed in frequency domain. Whereas, the smooth response for Butterworth and half cosine tapering was due to the fact that the convolution is done in frequency domain and the response is also being viewed in the frequency domain. Thus the jitters in time domain

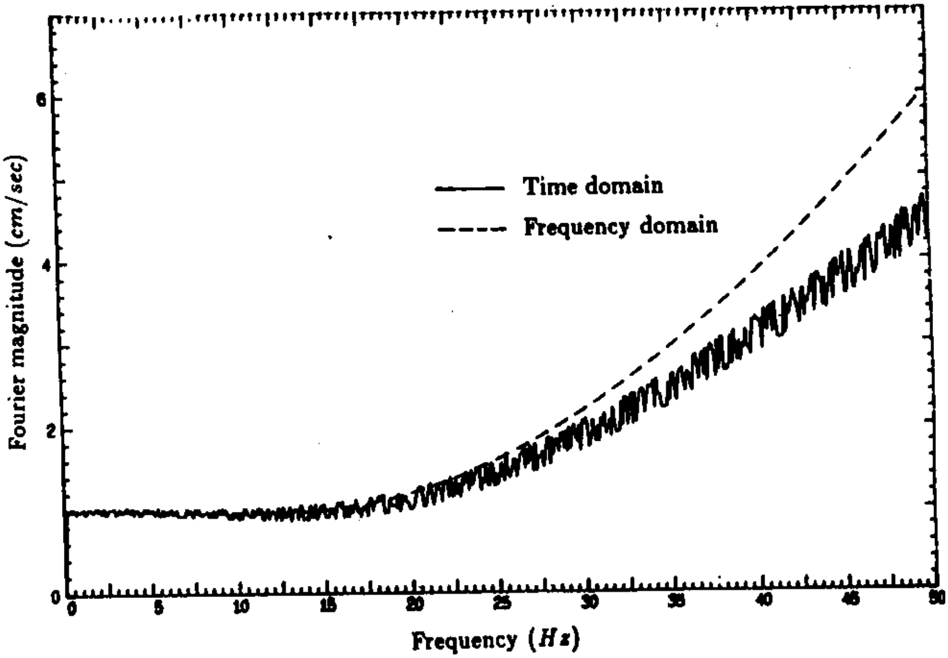

Figure 4: Comparison of response to white noise between instrument correction in time domain and frequency domain

convolution should not be taken as a drawback. However, the fact remains that the process of convolution in frequency domain can be physically explained easily.

OVERALL PERFORMANCE

Next, a white noise input is given as uncorrected accelerogram to all the four schemes with same accelerometer specifications as used earlier. The cut off frequency of high pass filter is taken as 0.1 Hz with roll off of 0.02 Hz (if required) and cut off frequency of low pass filter is taken as 25 Hz with a roll off of 2 Hz (if required). Trifunac scheme determines the corrected sequence at 50 SPS whereas $BLACS$, Erdik scheme and Khemici scheme determine the corrected sequence at 100 SPS. It is assumed that the user of the accelerogram needs the data at 200 SPS. The corrected sequence obtained from the proposed scheme is band limited interpolated using method described by Basu *et. al* (1992) to double the sampling rate. The corrected sequence obtained from Trifunac scheme is linearly interpolated to increase the sampling rate by four times while in Erdik scheme and Khemici scheme it is linearly interpolated to double the sampling rate. Fourier spectra of 200 SPS sequence thus obtained for the four schemes are determined and plotted one over the other as shown in Fig. 6. This figure indicates the effect of linearly interpolating the sequence. The three schemes which are linearly interpolated have lost substantial amount of energy from the original frequency band and instead have high frequency replicates. The worst effected is Trifunac scheme

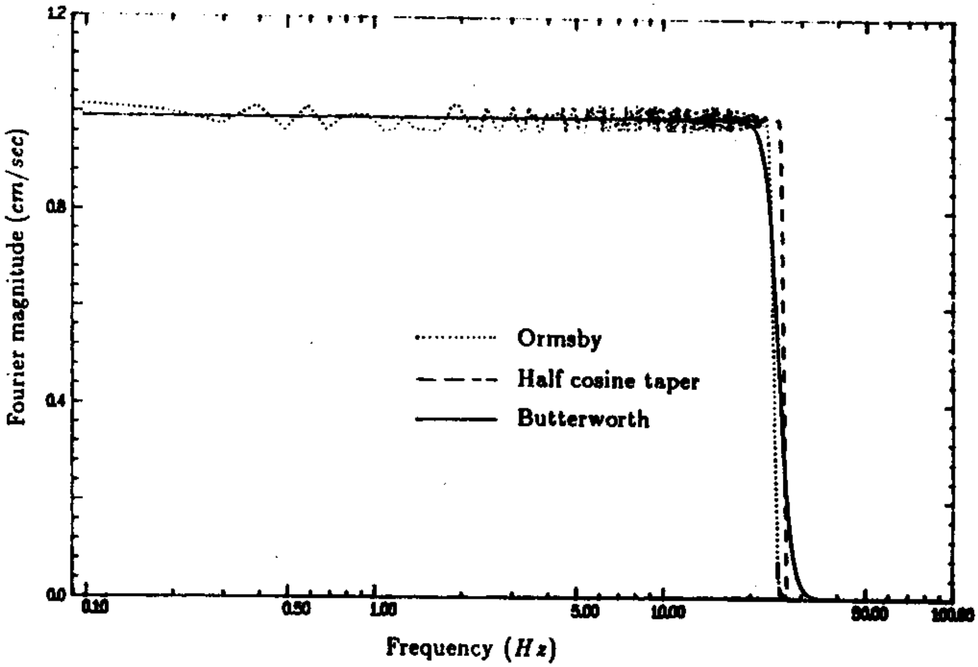

Figure 5: Comparison of response to white noise between Ormsby, half cosine taper and Butterworth low pass filters

where the the sampling rate was increased four times as it now has three additional replicates in high frequency at the cost of lowering the contribution of the original frequency content. Khemici scheme and Erdik scheme in which the sampling rate is doubled, show one additional replicate at the higher frequency at the cost of lowering the contribution of frequency contents of the original data. In contrast, *BLACS* show perfect and ideal overall performance and preserves frequency contents of the data.

COMPARATIVE STUDY OF SCHEMES TO EARTHQUAKE SIGNAL

In this part of the work, four uncorrected accelerograms are corrected by the four schemes. The uncorrected accelerograms are N-S component Imperial valley earthquake of May 18, 1940 recorded at El Centro (EERL 70-20, file 1); N05W component of Parkfield earthquake of June 27, 1966 recorded at Cholame, Shandon (EERL 70-21, file 40); N21E component of Kern County California earthquake of July 21, 1952 recorded at Taft Lincoln School Tunnel (EERL 70-20, file 10) and S72W component of Uttarkashi earthquake of October 20, 1991 recorded at Uttarkashi (Report no. Eq. Studies 93-07 of Department of Earthquake Engineering, University of Roorkee). The corrected accelerograms of all the schemes are obtained at 200 *SPS*. Table 1 summarizes the methods of interpolations and the cut off frequencies used by different schemes.

Table 2 gives details of accelerometer specifications and cut off frequency of low

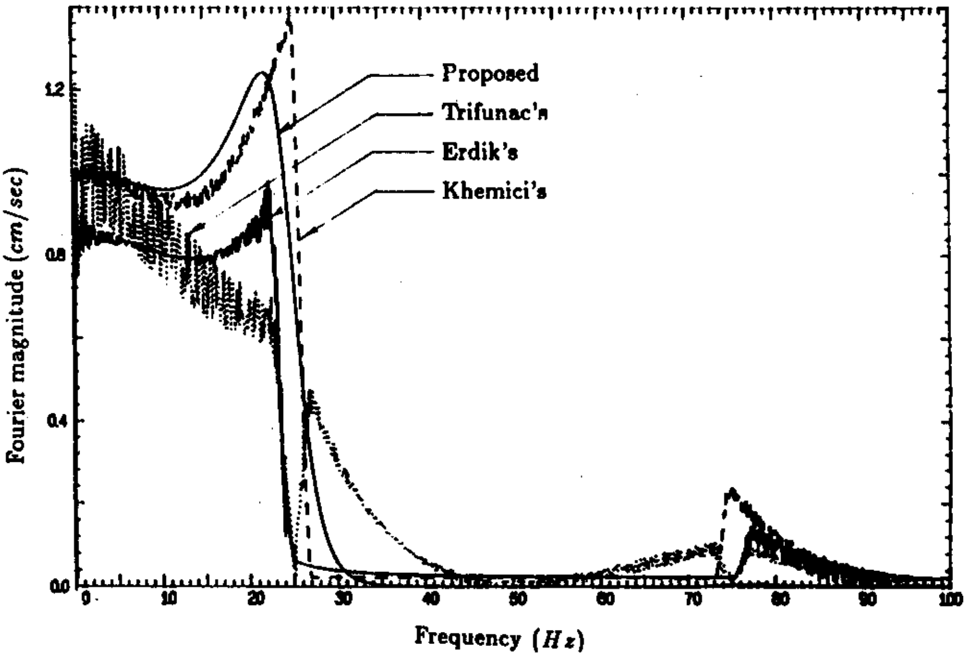

Figure 6: Comparison of response to white noise between proposed, Trifunac's, Erdik's and Khemici's schemes for corrected sequence of 200 *SPS*

Table 1: Summary of Type of Interpolation and Cut off Frequencies Used in Various Schemes

Scheme	Interpolation of Nonuniform Samples	Cut Off Frequencies (Hz) (roll off if required)		Sampling Rate Expander (Initial SPS, Final SPS)
		High Pass	Low Pass	
BLACS	Band Limited	0.07	< 0.5 (Av. *SPS*)	Band Limited (100,200)
Khemici	Linear	0.07 (0.05)	25.00 (2.00)	Linear (100,200)
Trifunac	Linear	0.07 (0.05)	25.00 (2.00)	Linear (50,200)
Erdik	Linear	0.07	25.00 (2.00)	Linear (100,200)

pass filter (ω_L) used in *BLACS* for different earthquakes.

Table 2: Cut off Frequency of Low Pass Filter of BLACS & Accelerometer Specifications

Earthquake	ω_L (Hz)	Accelerometer Specifications	
		ω_n (Hz)	ζ (% of critical)
El Centro	9.00	10.00	55.2
Parkfield	11.00	19.65	37.0
Taft	8.50	12.35	57.4
Uttarkashi	25.00	24.50	59.0

The maximum values of the acceleration, velocity and displacement as well as the time of their occurence are compared in a tabular form for the four earthquakes. The Fourier magnitudes of corrected accelerograms of all the four schemes are determined and are compared for the four corrected accelerograms. Response spectra for 2% damping for the four earthquakes are computed for *BLACS* and for Trifunac scheme and are plotted one over the other for comparison.

Comparison of Maximum Motion

Tables 3 to 6 give the values of maximum acceleration, velocity and displacements along with time of their occurrence determined through four schemes for El Centro, Parkfield, Taft and Uttarkashi earthquakes respectively. These tables show that the maximum value of acceleration and their time of occurrence determined through all the four schemes match quite well. However, there are differences in derived maximum velocity and their time of occurrence and there are substantial differences in the derived maximum displacements and their time of occurrence. The differences in maximum velocity and maximum displacements have occurred due to the fact that the cutoff frequency of high pass filter has not been properly selected. If the cutoff frequency of high pass filter is increased then the results of maximum velocity and maximum displacements from the four schemes comes out to be the same. However, neither of the two yield true velocity or displacement due to the simple fact that at very low frequency, noise is more than the signal and in integration the very low frequency contents dominate. Thus increasing cutoff frequency of high pass filter may give uniform results of maximum velocity and displacement for four schemes but these results will not be realistic.

Comparison in Frequency Domain

A frequency domain comparison of the corrected accelerograms at 200 *SPS* obtained from four different schemes is also done. For this purpose, Fourier transformation of the corrected accelerograms is taken. The entire band upto 100 Hz (Nyquist frequency) is

Table 3: Maximum Motion for El Centro Accelerogram

Scheme	Max. Acceleration		Max. Velocity		Max. Displacement	
	Value (*gals*)	Instant (*sec*)	Value (*cm/sec*)	Instant (*sec*)	Value (*cm*)	Instant (*sec*)
BLACS	352.96	2.18	63.06	2.24	78.09	2.77
Khemici	399.07	2.24	39.83	2.23	22.37	1.11
Trifunac	394.60	2.14	44.54	2.20	53.93	53.74
Erdik	355.18	2.44	36.71	2.18	17.91	8.60

Table 4: Maximum Motion for Parkfield Accelerogram

Scheme	Max. Acceleration		Max. Velocity		Max. Displacement	
	Value (*gals*)	Instant (*sec*)	Value (*cm/sec*)	Instant (*sec*)	Value (*cm*)	Instant (*sec*)
BLACS	352.05	7.43	21.50	7.53	12.05	1.17
Khemici	359.34	7.41	22.17	7.52	6.38	10.66
Trifunac	360.92	7.42	23.39	7.52	5.18	10.66
Erdik	313.82	7.40	23.04	7.50	4.88	5.84

Table 5: Maximum Motion for Taft Accelerogram

Scheme	Max. Acceleration		Max. Velocity		Max. Displacement	
	Value (*gals*)	Instant (*sec*)	Value (*cm/sec*)	Instant (*sec*)	Value (*cm*)	Instant (*sec*)
BLACS	198.68	9.19	21.11	9.55	16.75	2.96
Khemici	172.16	9.14	14.62	3.44	13.44	53.44
Trifunac	169.80	9.12	16.39	3.42	7.53	49.26
Erdik	146.16	9.10	15.87	3.41	7.86	49.28

Table 6: Maximum Motion from Uttarkashi Accelerogram

Scheme	Max. Acceleration		Max. Velocity		Max. Displacement	
	Value (*gals*)	Instant (*sec*)	Value (*cm/sec*)	Instant (*sec*)	Value (*cm*)	Instant (*sec*)
BLACS	508.00	5.15	31.56	5.05	42.86	30.47
Khemici	498.19	5.13	24.84	24.10	40.77	22.67
Trifunac	518.80	5.12	31.52	5.04	51.09	35.84
Erdik	481.50	5.10	29.45	5.02	37.49	30.55

Table 7: Comparison of Schemes for El Centro Accelerogram

Frequency Segment		Mean of Magnitude			
Begin (*Hz*)	End (*Hz*)	Trifunac (*dB*)	Khemici (*dB*)	Erdik (*dB*)	BLACS (*dB*)
0.000	2.478	40.093	39.838	38.608	41.073
2.490	4.968	36.674	36.625	35.427	37.233
4.980	7.458	32.367	32.567	31.399	33.550
7.471	9.949	28.678	29.230	28.139	26.063
9.961	12.439	25.722	26.808	25.789	8.735
12.451	14.929	25.489	27.248	25.929	-14.610
14.941	17.419	25.603	27.999	26.771	-17.458
17.432	19.910	24.009	27.297	26.013	-18.667
19.922	22.400	23.370	27.824	26.104	-19.682
22.412	24.890	18.237	28.050	22.559	-20.514
0.000	25.000	30.435	31.590	30.117	28.158
24.902	37.402	14.976	5.829	12.266	-22.295
37.415	49.915	-0.150	-33.581	7.564	-25.672
49.927	62.427	-4.932	-35.489	5.393	-36.699
62.439	74.939	3.746	-9.942	4.330	-54.242
74.951	87.471	2.335	7.496	7.605	-68.327
87.463	99.963	-8.742	-8.130	3.023	-33.833
25.012	100.00	4.756	-1.769	7.214	-31.187
0.000	100.000	19.656	20.094	19.768	16.148

Table 8: Comparison of Schemes for Parkfield Accelerogram

Frequency Segment		Mean of Magnitude			
Begin (Hz)	End (Hz)	Trifunac (dB)	Khemici (dB)	Erdik (dB)	BLACS (dB)
0.000	2.478	33.783	33.631	32.368	33.689
2.490	4.968	32.783	32.711	31.482	32.860
4.980	7.458	25.606	25.746	24.581	26.637
7.471	9.949	21.086	21.618	20.445	22.300
9.961	12.439	20.682	21.624	20.471	16.841
12.451	14.929	13.300	14.902	13.629	-6.617
14.941	17.419	11.438	13.909	12.404	-35.432
17.432	19.910	12.157	15.774	13.830	-42.130
19.922	22.400	5.129	9.726	7.607	-43.565
22.412	24.890	0.131	9.790	1.717	-44.663
0.000	25.000	23.419	23.914	22.542	22.522
24.902	37.402	-0.226	-13.279	-21.011	-46.825
37.415	49.915	-6.225	-40.875	-25.631	-50.454
49.927	62.427	-11.019	-42.756	-27.807	-61.504
62.439	74.939	-10.818	-28.184	-29.030	-78.852
74.951	87.471	-12.504	-8.014	-10.952	-78.117
87.463	99.963	-14.798	-14.273	-15.185	-38.700
25.012	100.00	-7.770	-17.005	-18.988	-49.445
0.000	100.000	12.071	12.108	10.719	10.490

Table 9: Comparison of Schemes for Taft accelerogram

Frequency Segment		Mean of Magnitude			
Begin (Hz)	End (Hz)	Trifunac (dB)	Khemici (dB)	Erdik (dB)	BLACS (dB)
0.000	2.478	34.135	33.956	32.696	34.346
2.490	4.968	32.623	32.578	31.342	34.023
4.980	7.458	27.925	28.095	26.907	31.684
7.471	9.949	20.139	20.637	19.458	21.001
9.961	12.439	15.812	16.850	15.612	-3.964
12.451	14.929	11.930	13.776	12.390	-25.539
14.941	17.419	9.862	12.450	11.037	-27.378
17.432	19.910	7.905	11.419	9.838	-28.758
19.922	22.400	7.402	11.884	10.210	-29.865
22.412	24.890	2.641	12.171	6.367	-30.773
0.000	25.000	23.377	23.851	22.492	23.647
24.902	37.402	-0.669	-9.119	-5.653	-32.654
37.415	49.915	-7.930	-31.376	-10.411	-36.095
49.927	62.427	-12.147	-34.636	-12.617	-47.130
62.439	74.939	-11.742	-24.961	-13.808	-64.621
74.951	87.471	-13.214	-8.052	-9.051	-78.542
87.463	99.963	-16.226	-15.717	-12.828	-38.089
25.012	100.00	-8.689	-15.743	-10.286	-40.544
0.000	100.000	11.965	12.082	11.032	11.625

Table 10: Comparison of Schemes for Uttarkashi accelerogram

Frequency Segment		Mean of Magnitude			
Begin (Hz)	End (Hz)	Trifunac (dB)	Khemici (dB)	Erdik (dB)	BLACS (dB)
0.000	2.478	33.069	33.079	31.550	33.276
2.490	4.968	35.806	35.772	34.567	38.159
4.980	7.458	33.851	34.326	32.841	35.967
7.471	9.949	34.096	35.020	33.466	33.731
9.961	12.439	31.860	32.873	31.702	32.484
12.451	14.929	28.204	30.127	28.598	30.569
14.941	17.419	24.438	27.041	25.433	29.861
17.432	19.910	23.188	26.609	25.244	27.412
19.922	22.400	18.125	23.077	21.614	23.714
22.412	24.890	12.191	22.293	18.740	20.635
0.000	25.000	29.918	31.149	29.659	31.899
24.902	37.402	12.314	0.168	9.402	5.700
37.415	49.915	4.267	-28.396	4.673	-32.115
49.927	62.427	-1.048	-31.198	2.508	-43.533
62.439	74.939	1.970	-15.769	1.441	-32.855
74.951	87.471	0.149	4.739	5.396	-24.138
87.463	99.963	-4.485	-3.585	1.595	-30.177
25.012	100.00	4.005	-4.602	4.620	-9.586
0.000	100.000	19.110	19.529	18.971	20.081

divided into 16 segments. Frequency band upto 25 Hz is divided into 10 equal segments and frequency band between 25 Hz and 100 Hz is divided into 6 equal segments. Mean Fourier magnitude in each band for the four schemes is determined and is presented in Tables 7 to 10 for El Centro, Parkfield, Taft and Uttarkashi earthquakes earthquakes respectivily.

For El Centro, Parkfield and Taft accelerograms, in all the frequency segments which are above the cut off frequency of low pass filter (ω_L) of $BLACS$ (Table 2), the Fourier magnitude of $BLACS$ is much smaller than those of the other three schemes. For these earthquakes, in most of the segments of frequencies less than ω_L, the mean Fourier magnitude is more in $BLACS$ in comparison to other three schemes. For Uttarkashi earthquake the cut off frequency of low pass filter is same (25 Hz) for all the schemes. For this earthquake also, in most of the frequency segments less than 25 Hz the mean Fourier magnitude obtained from $BLACS$ is more than that of other schemes while for most of the frequency segments greater than 25 Hz these three schemes indicate higher values than $BLACS$. These results, thus clearly prove superiority of $BLACS$ over other schemes, as other schemes have larger energy in stop band at the cost of reducing energy from the pass band.

Comparison of Response Spectra

Response spectra for 2% damping is obtained from corrected accelerogram of $BLACS$ and that of Trifunac scheme for all the four earthquakes discussed above and Figs. 7 to 10 show the comparison. In the low period side (high frequency) comparison for El Centro, Parkfield and Taft (Figs. 7, 8 & 9) show the effect of using wrong cut off frequency of low pass filter in Trifunac scheme (which more or less represents all the scheme for response spectra). The differences in high frequency are thus caused by effect of aliasing particularly during linear interpolation in the processing scheme of Trifunac. This effect has resulted into higher spectral acceleration in El Centro and Parkfield accelerogram but has resulted into smaller value in case of Taft accelerogram. In higher periods, El Centro, Taft and Uttarkashi response spectra show good amount of difference but Parkfield accelerogram shows surprisingly good matching. It can be concluded that in case band limited properties of the data is not properly preserved throughout the processing then the final effect on the resulting response spectra can be deceptive.

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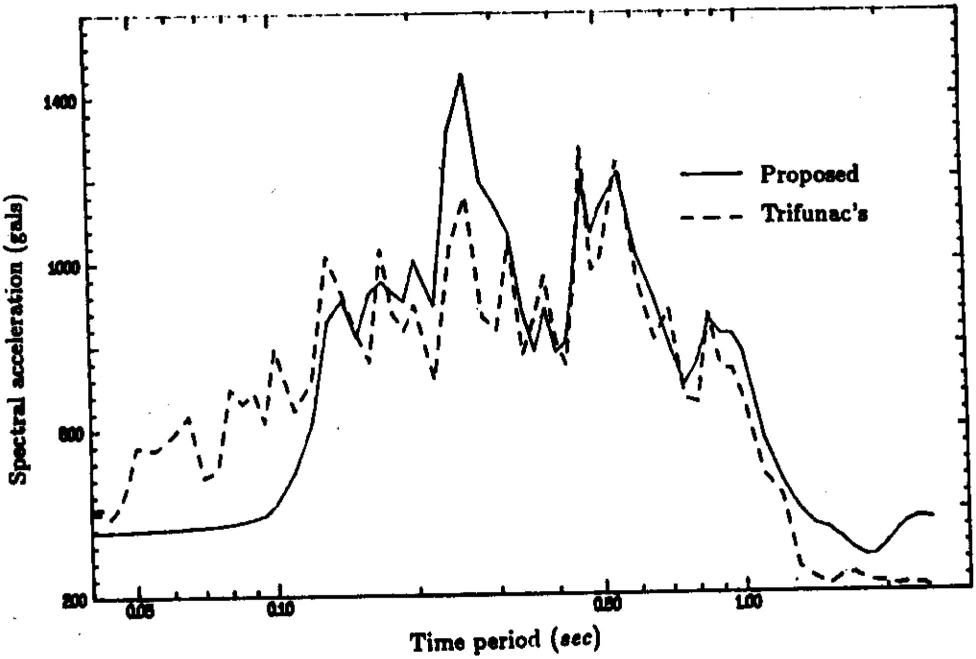

Figure 7: Comparison of response spectra (2% damping) determined from corrected accelerogram of BLACS and that from Trifunac's scheme for El Centro motion

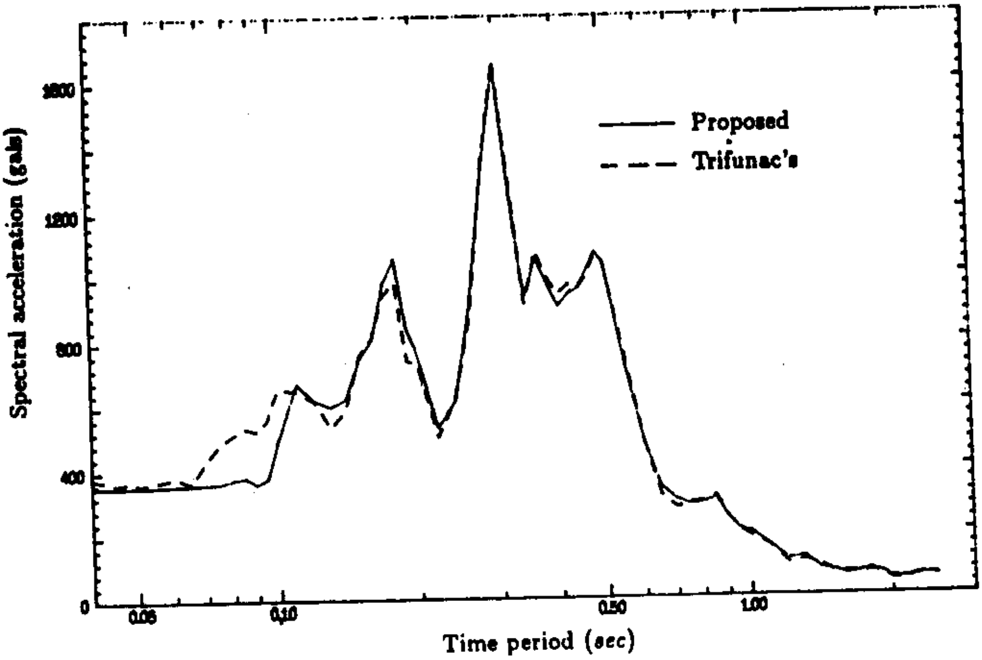

Figure 8: Comparison of response spectra (2% damping) determined from corrected accelerogram of BLACS and that from Trifunac's scheme for Parkfield motion

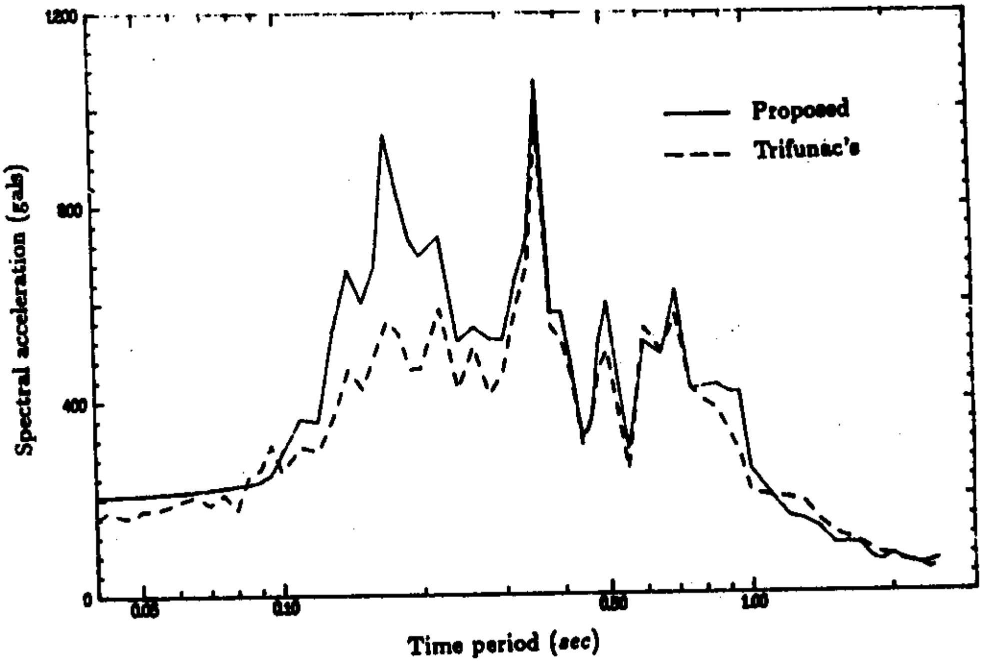

Figure 9: Comparison of response spectra (2% damping) determined from corrected accelerogram of BLACS and that from Trifunac's scheme for Taft motion

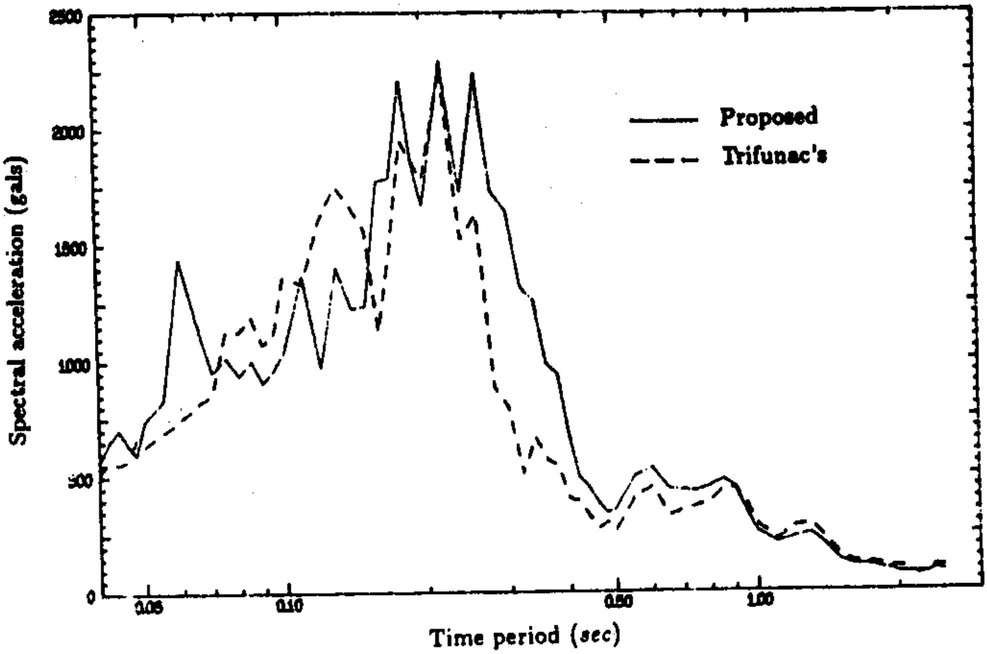

Figure 10: Comparison of response spectra (2% damping) determined from corrected accelerogram of BLACS and that from Trifunac's scheme for Uttarkashi motion

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